

SI APPENDIX

Provisioning services. The Canadian Census of Agriculture (see below for information on sources) provided data for crop and farm animal production at the scale of municipalities, which are referred to as Census Consolidated Subdivisions (CCSs) in the census. Based on the historical CCSs digital boundary files (available from 1981 to 2006, every five years) (1-6), we could see that over the eight census periods covered by our study, the administrative boundaries of the CCSs have changed. Because no digital boundary maps were available for 1971 and 1976, we created our own files by editing the 1981 digital map (1) to match paper maps for 1971 and 1976. In order to standardize the historical census data to the same spatial unit, we used the CCS digital boundary files for 2006 (6) as a reference to which all other CCS boundary maps were adjusted. The CCSs maps from 1971 to 2001 were individually overlaid with the 2006 reference map, and the overlapping boundaries were clipped to create polygons representing the smallest units of discrete area. We then re-aggregated the CCSs by reassigning each polygon and the proportionate value of the ES associated with its area, to match the 2006 boundaries.

Crop production (percentage of land in each municipality used for crop production).

We estimated the percentage of land under crop cultivation based on the area (in hectares) under crop provided in the census (9-16) and the total area of each municipality in 2006. We used this indicator because crop yield data were not available at this scale.

Farm animal production (number of animals per square kilometer). Farm animals comprised pig, cattle (including both beef and dairy cows) and poultry (including chickens, turkeys and other poultry production) (17-24). Data on farm production were unavailable for municipalities with too few farms, which are protected by a privacy law. Therefore, data on

farm production were unavailable for these municipalities. We were able to fill in these missing values only for pig production using the Quebec Ministry of Agriculture data for 2004 (approximated to 2006) (25).

Regulating services. Although regulating services support the delivery of other services, notably provisioning services, and are critical for the maintenance of human well-being over the long term, quantifying them is particularly challenging. The temporal dimension of our study made the task of finding data and deriving appropriate indicators even more complex.

Above-ground carbon sequestration (kilograms of carbon per square kilometer).

Above-ground carbon sequestration was estimated for each municipality based on a provincial forestry database called *système forestier d'information par tesselles* (SIFORT) (26). SIFORT is a geographic database derived from the provincial decennial forest inventories (*système d'information écoforésterie* data) (27) which started in the 1960's. The SIFORT database divides the study area into a mosaic of rectangular polygons (*i.e.*, “tesselles”) of 14 ha on average. Each polygon contains data on the dominant overstory tree species groups, projected crown density class, and tree height class. Based on this information, we used the conversion tables from Fournier et al. (28) for Quebec forests to associate stand attributes with biomass values. The method of Fournier et al. (28) is based on a simplifying tree species composition into more general classes. The relevant stand types for our study region were “mixed stands”, “shade tolerant deciduous trees”, “shade intolerant deciduous trees”, and “other coniferous trees”. We used a factor of 0.5 to convert biomass estimates to carbon sequestered (29) and overlaid the map of municipality boundaries and forest maps to obtain data at the municipality scale. Because the inventories are decennial, we determined the date at which the data were published for our study region by examining

the hard copy of the SIEF inventories for the first (1970) and second inventories (1984). For the third and fourth inventories, the geodatabases were created between 1991 and 1997 and between 2006 and 2009 respectively. We chose the most conservative dates, 1991 for the third and 2006 for the fourth inventory. Finally, we used a linear interpolation between years to obtain data for the entire period of time, with a time step of five years.

Flood regulation. The regulation of floods by ecosystems was the most challenging service to quantify through space and time. We used data compiled by the Quebec Ministry of Public Security on the occurrence of flooding events in each municipality since 1974 (30), supplemented with archival data from Statistics Quebec for 1971 and 1972 (31-32). To smooth out short-term fluctuation in the number of flood events through the time series, we calculated a moving average and maximum over five-year periods. We used the difference between the maximum and the average number of flood events calculated per municipality, by periods of five years, to reflect the amplitude of flood events during this period. Because high amplitude values reflect a low ecosystem capacity to buffer variation in flooding events through time, we reversed this indicator by calculating the difference between the maximum amplitude value for the entire data set and the value obtained for each municipality.

Although most municipalities in this region have rivers that are capable of flooding and our amplitude approach limits the effect of the size of the river running through each municipality on the number of flooding events, we were not able to take into account the relative probability of flooding for each municipality.

Cultural services.

Hunting (number of animals killed through hunting per square kilometer). We obtained information on the location and the species identity of each animal killed during game

hunting activities from 1971 to 2006 from the Quebec Ministry of Forests, Fauna and Parks (33). The whitetail deer was the predominant hunted species (representing 98% of the kills) in the region and over the entire time period. The database also reported kills of wild turkeys (1.4%), moose (0.1%), black bears (0.16%) and coyotes (0.02%). Because the data were reported yearly, we calculated the sum of animals killed per five-year periods.

Campgrounds (number of campgrounds per square kilometer). Beginning in 1963, a provincial association of camping, together with the Quebec Ministry of Tourism have published booklets (34-54) (updated every one to three years) with detailed information about the location and capacity of each campground in the province. After digitizing the data for the study region, we aggregated the data by averaging the number of campgrounds over five year periods. For example, data for 1972 and 1975 were averaged for the period 1971-1975.

Recreation activities (number of winter and/or summer outdoor activities per square kilometer). The number of hiking, snowshoeing, skating and alpine skiing sites in each municipality were compiled using multiple tourism guides. Because administrative boundaries divide our study region into two tourism divisions, we compiled data from guides of the regional associations of tourism of Montérégie and Estrie (published respectively from 1986 and 1988 to 2006) (55-78), as well as booklets published by the former Quebec Ministry of Tourism on cross-country skiing and snowshoeing from 1973 to 1987 (79-89), and downhill skiing from 1971 to 1987 (90-103), the latest being complemented by the recent Ulysse tourism guide (104). For hiking, the *Fédération québécoise de la marche* has published a guide of trails since 1977 (105-113). After digitizing and compiling all the data,

we calculated the average number of activities per municipality and over periods of five years.

Socio-economic and biophysical attributes of the region.

Population density (Number of inhabitants per square kilometer). The Canadian Census of Population (114-118) provided data for number of inhabitants at the CCS scale. We used the same methodology as explained in the “provisioning services” section above in order to standardize the historical census data to the same spatial unit.

Distance to Montreal (Kilometers). The CSD digital boundary shapefile for 2006 (ref) represented each municipality as a polygon. We calculated the distance between the geometric center of each polygon and the city of Montreal.

Soil capability for agriculture. The Canadian Land Inventory (119) comprised maps representing the spatial distribution of seven classes of mineral soils. These classes were determined based on soil potential and limitations for agriculture (adverse climate, low fertility, salinity, topography limitation, inundation by streams or lakes etc.) to rate the agricultural land capability. Soils classed as 0 were organic soils. Classes from 1 to 4 referred to soils considered capable of sustained use for cultivated field crops with increasing degree of limitations from class 1 to 4. Soils in classes 5 and 6 referred respectively to severe limitation for or capable only of producing perennial forage crops. Finally, soils of class 7 were not capable of producing any kind of crop. For each municipality of the Montérégie, we determined the dominant soil class, *i.e.*, which covered the most area.

Data accessibility

Ecosystem service estimates, socioeconomic and biophysical attributes for each municipality, for each date, are available on Dryad: <http://dx.doi.org/10.5061/dryad.g4590>.

For data protected by licence agreements, a data request should be made to the specific agencies:

(i) Historical pork production, contact La Direction régionale de la Montérégie du Ministère de l'Agriculture et de l'Alimentation du Québec (MAPAQ), 1355, rue Johnson Ouest, bureau 3300 Saint-Hyacinthe (Québec) J2S 8W7, Canada.

<http://www.mapaq.gouv.qc.ca/fr/Regions/monteregie/Pages/monteregie.aspx>

(ii) Location of animal killed during hunting activities in the Montérégie, contact

Faune Québec. Direction de l'expertise sur la faune et ses habitats

Ministère du Développement Durable, de l'Environnement, de la Faune et des Parcs

(MDDELCC), 800 chemin de Sainte-Foy, 2e étage, Québec (Québec) G1S 4X4, Canada

http://www.mddelcc.gouv.qc.ca/ministere/rejoindr/adr_reg.htm

(iii) Data used to estimate carbon storage, e.g SIFORT "Système d'Information FORestière

par Tesselle", contact Ministère des Forêts, de la Faune et des Parcs (MFFP), 5700, 4e

Avenue Ouest, A 409 Québec (Québec) G1H 6R1, Canada. Email:

services.clientele@mffp.gouv.qc.ca. <http://www.mffp.gouv.qc.ca/accueil.jsp>

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6. Statistics Canada (2006) *Census Consolidated Subdivisions, digital boundary file, 2006 Census* (Statistics Canada, Ottawa).
7. Statistics Canada (1971) Reference map C-7, Quebec part 3, by Census Division, Census Subdivision, largest city, Census Metropolitan Area, Census Agglomeration. In 1971 Census of Agriculture (catalogue 96-706, Volume 4, part 2).
8. Statistics Canada (1976) Reference map, Quebec part 1, by Census Division, Census Subdivision, largest city, Census Metropolitan Area. In 1976 Census of Agriculture (catalogue 96-805, Volume 12).
9. Statistics Canada (1971) Land in crops by hectare, by province, Census Consolidated Subdivision (CCS), 1971 Quebec (Table A). In 1971 Census of Agriculture, age of farm operator, length of residence, operating arrangements, land use, tenure, farm size, by province, Census Agricultural Region (CAR), Census Division (CD) and Census Consolidated Subdivision (CCS).
10. Statistics Canada (1976) Land in crops by hectare, by province, Census Consolidated Subdivision (CCS), 1976 Quebec (Table A). In 1976 Census of Agriculture, age of farm operator, length of residence, operating arrangements, land use, tenure, farm size, by province, Census Agricultural Region (CAR), Census Division (CD) and Census Consolidated Subdivision (CCS).
11. Statistics Canada (1981) Land in crops by hectare, by province, Census Consolidated Subdivision (CCS), 1981 Quebec (Table 5). In 1981 Census of Agriculture, land use farm size (improved lands), land management practices, by province, Census Agricultural Region (CAR), Census Division (CD) and Census Consolidated Subdivision (CCS).
12. Statistics Canada (1986) Land in crops by hectare, by province, Census Consolidated Subdivision (CCS), 1986 Quebec (Table 2). In 1986 Census of Agriculture, land tenure, land use and farm size, by province, Census Agricultural Region (CAR), Census Division (CD) and Census Consolidated Subdivision (CCS).
13. Statistics Canada (1991) Land in crops by hectare, by province, Census Consolidated Subdivision (CCS), 1991 Quebec (Table 1). In 1991 Census of Agriculture, operating arrangements, land use and land management practices, by province, Census Agricultural Region (CAR), Census Division (CD) and Census Consolidated Subdivision (CCS).
14. Statistics Canada (1996) Land in crops by hectare, by province, Census Consolidated Subdivision (CCS), 1996 Quebec (Table 7). In 1996 Census of Agriculture, land tenure, land use and land management practices, by province, Census Agricultural Region (CAR), Census Division (CD) and Census Consolidated Subdivision (CCS).
15. Statistics Canada (2001) Land in crops (excluding Christmas tree area) by hectare, by province, Census Consolidated Subdivision (CCS), 2001 Quebec (Table 5). In 2001 Census of Agriculture, land use, by province, Census Agricultural Region (CAR), Census Division (CD) and Census Consolidated Subdivision (CCS).
16. Statistics Canada (2006) Land in crops (excluding Christmas tree area) by hectare, by province, Census Consolidated Subdivision (CCS), 2006 Quebec. In 2006 Census of

Agriculture, tenure & land use, by province, Census Agricultural Region (CAR), Census Division (CD) and Census Consolidated Subdivision (CCS).

17. Statistics Canada (1971) Total number of pigs, cattle and calves, dairy cows, geese, turkeys, hens and chickens, by province, Census Consolidated Subdivision (CCS), 1971 Quebec (Table E). In 1971 Census of Agriculture, poultry and livestock, by province, Census Agricultural Region (CAR), Census Division (CD) and Census Consolidated Subdivision (CCS).
18. Statistics Canada (1976) Total number of pigs, cattle and calves, dairy cows, geese, turkeys, hens and chickens, by province, Census Consolidated Subdivision (CCS), 1976 Quebec (Table C). In 1976 Census of Agriculture, Poultry and Livestock, by province, Census Agricultural Region (CAR), Census Division (CD) and Census Consolidated Subdivision (CCS).
19. Statistics Canada (1981) Total number of pigs, cattle and calves, dairy cows, geese, turkeys, hens and chickens, by province, Census Consolidated Subdivision (CCS), 1981 Quebec (Table 6). In 1981 Census of Agriculture, poultry and livestock, by province, Census Agricultural Region (CAR), Census Division (CD) and Census Consolidated Subdivision (CCS).
20. Statistics Canada (1986) Total number of pigs, cattle and calves, dairy cows, turkeys, hens and chickens, other poultry, by province, Census Consolidated Subdivision (CCS), 1986 Quebec (Table 5). In 1986 Census of Agriculture, poultry and livestock, by province, Census Agricultural Region (CAR), Census Division (CD) and Census Consolidated Subdivision (CCS).
21. Statistics Canada (1991) Total number of pigs, cattle and calves, dairy cows, turkeys, hens and chickens, other poultry, by province, Census Consolidated Subdivision (CCS), 1991 Quebec (Table 5). In 1991 Census of Agriculture, poultry, livestock and bee colonies, by province, Census Agricultural Region (CAR), Census Division (CD) and Census Consolidated Subdivision (CCS).
22. Statistics Canada (1996) Total number of pigs, cattle and calves, milk cows, turkeys, hens and chickens, other poultry, by province, Census Consolidated Subdivision (CCS), 1996 Quebec (Table 14). In 1996 Census of Agriculture, poultry, livestock and bee colonies, by province, Census Agricultural Region (CAR), Census Division (CD) and Census Consolidated Subdivision (CCS).
23. Statistics Canada (2001) Total number of pigs, cattle and calves, dairy cows, turkeys, hens and chickens, other poultry, by province, Census Consolidated Subdivision (CCS), 2001 Quebec (Table d). In 2001 Census of Agriculture, poultry, livestock and bee colonies, machinery, by province, Census Agricultural Region (CAR), Census Division (CD) and Census Consolidated Subdivision (CCS).
24. Statistics Canada (2006) Total number of pigs, cattle and calves, dairy cows, turkeys, hens and chickens, other poultry, by province, Census Consolidated Subdivision (CCS), 2006 Quebec. In 2006 Census of Agriculture, poultry, livestock and colonies of bees, by province, Census Agricultural Region (CAR), Census Division (CD) and Census Consolidated Subdivision (CCS).

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Table S1. Moran's I index values calculated per year with associated z-scores and p-values.

Moran's I was used in order to examine the spatial distribution of ES bundles (clustered, dispersed, or random) and changes in this spatial distribution through time. Positive values revealed a tendency toward clustering of ES bundles and the z-scores and p-values indicated that we can reject the null hypothesis that bundle types are randomly distributed across the study area at all time steps.

Years	Moran's I	Z-scores	p-values
1971	0.11	2.40	0.020
1976	0.15	2.99	0.003
1981	0.11	2.31	0.020
1986	0.18	3.60	<0.001
1991	0.27	5.46	<0.001
1996	0.29	5.85	<0.001
2001	0.22	4.35	<0.001
2006	0.24	4.80	<0.001

Fig S1. Change in the provision of all ES through time (mean \pm SD across all municipalities).

Each ES was standardized to unit variance to allow comparison among the values. Results of the space-time interaction (STI) analysis performed for each ES are presented below the corresponding plot. The independent tests for spatial and temporal structures were abbreviated S and T respectively. We used $\alpha = 0.05$ and the p -value was calculated after 999 permutations. A significant STI indicates that the temporal change of a given ES was not the same in all municipalities.

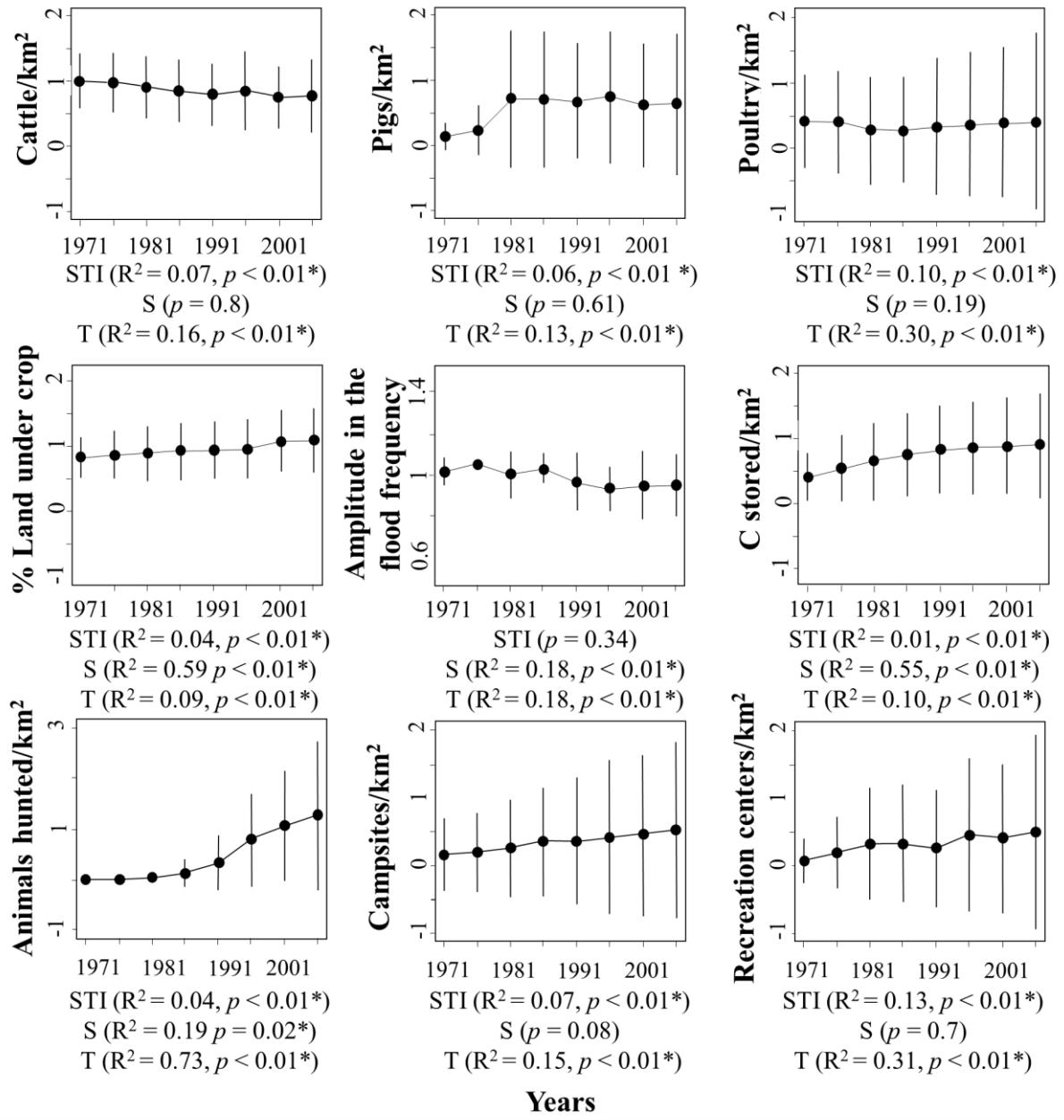


Fig S2. Redundancy analysis controlled for the effect of time. Colors of the points represent the ES bundles identified through k-means analysis.

